MESCAL

Mangrove Ecosystems for Climate Change Adaptation and Livelihoods

MESCAL Fisheries Surveys:
Review: Approaches used for assessing functional relationship between mangroves and fish fauna output, and identify the most suitable approach for use in the Pacific

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Background

Mangrove habitats play a number of vital roles for many species of fish and crustaceans. It is widely accepted that the ecological services delivered by mangroves are often critical for sustaining productivity in coastal fisheries (Manson et al. 2005a, Aburto-Oropeza et al. 2008). Although much of the research supporting this paradigm is based on commercial fisheries data, mangrove value should not be underestimated in terms of inputs to artisanal and subsistence fisheries (Hussain & Badola 2010). Positive correlations between the presence and/or aerial extent of nearby mangroves and fisheries productivity have been widely reported (Manson et al. 2005a, Sheaves et al. in press). In addition, mangrove habitats influence fish community structure in neighbouring habitats/ecosystems (Olds et al. 2012) through increases in biomass of fish and invertebrates that spend part of their life cycles in mangrove habitats (Aburto-Oropeza et al. 2008). Consequently, the ecological services that mangrove systems provide for many fisheries species results in a high, but frequently undervalued input into local fisheries (Barbier 2000, O'Garra 2012).

Mangrove habitats are typically characterised by high abundances of fish and crustaceans with some areas known to have four to ten times higher fish abundances than neighbouring habitats (Robertson & Duke 1990b, Roennbaeck 1999). In addition, it is widely reported that mangrove habitats function as nursery areas for fish and crustaceans (Laegdsgaard & Johnson 1995, Sala et al. 2002) so play a vital role in producing future adult populations (Sheaves et al. 2006a). Although we have a general understanding of mangrove-fish associations it is far from complete and we lack sound understanding of the full range of species that utilise mangrove habitats and have little understanding of the services that mangroves provide to fish, i.e. the functional roles mangroves play in life histories of fish (Johnston & Sheaves 2007). Consequently, in the face of continued reductions in mangrove extent, there is an imperative to better understand their role in fisheries productivity and sustainability, particularly among Pacific nations where food security for growing populations is an important issue. To this end, we evaluate approaches that can be used to assess functional relationships between fish and mangroves and assess their utility for application in the Pacific.

Functional roles of mangroves

We have identified five key functional roles performed by mangroves; nursery area, refuge, nutrient transfer, feeding and connectivity (Fig. 1). All roles are potentially vital for particular life history phases of some species but for most species the level of dependence on mangroves per se remains unclear (Loneragan et al. 2005, Sheaves & Johnston 2009). Furthermore, it is unknown whether the roles of mangroves remain consistent among different mangrove settings. All five roles are at least important, if not vital, for a number of species, and roles need not be mutually exclusive among species or mangrove settings. Our focus in this review is not directly on specific species-mangrove relationships, rather we focus on the various approaches that may help to fill some of the gaps in our understanding of each of the five roles. To determine functional roles of a habitat it is necessary to determine which species of fish use the habitat. Consequently it is necessary to effectively sample the habitat to reliably represent the fish assemblage. Data collections to investigate the fish-functional role relationships can take a direct approach by collecting fish from the habitat and/or through an indirect approach using chemical techniques. Direct approaches allow data to be related to specific sites and times whereas chemical approaches elucidate more general, but not necessarily less accurate, habitat linkages. Indirect chemical approaches also require capture of fish, however it is not always essential that fish are captured directly from the habitat being investigated to allow construction of a history of habitat use (Chittaro et al. 2004).

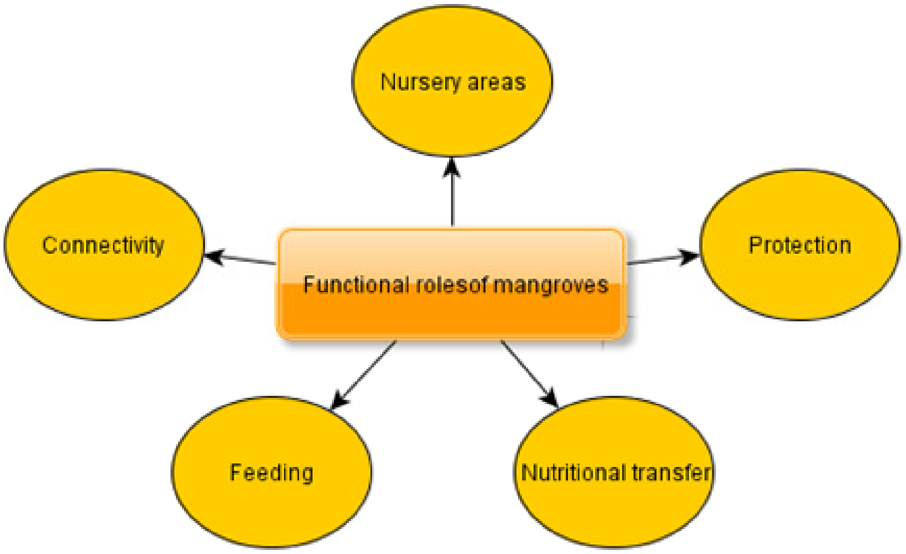

Figure 1: Functional roles of mangroves in fisheries output.

Nursery areas:

Primarily, mangroves have been considered nursery grounds because of the high abundances of small and juvenile fish associated with them (Blaber & Blaber 1980, Robertson & Duke 1987). Juvenile fish are said to gain advantage from utilisation of mangrove habitats through reduced predation and abundant food resources (Laegdsgaard & Johnson 2001, Meynecke et al. 2007), factors that increase survivorship and growth rates (Manson et al. 2005b). One reason why so little is known about mangrove roles is because conventional fish sampling approaches are either very difficult, or impossible, to use effectively in the complex structure provided by mangroves. Consequently use of mangroves is usually implied from sampling immediately adjacent to mangroves (Robertson & Duke 1987), essentially association by proximity, using some form of block net. This technique assumes that fish trapped by the net were exiting, or at least using the fringe/edge, of mangrove forests. This remains the most efficient netting approach for determining which species use mangroves.

Conventionally, data used to determine whether a habitat is used as a nursery area is size distribution data, however chemical approaches are proving to be very useful alternatives (Nagelkerken 2007, Geffen et al. 2011) (Fig. 2). Fish collections provide size distribution data as well as specimens for chemical analysis of otoliths. Published literature or dissections of collected fish can then be used to determine whether fish are juvenile or adult. Such collections usually require netting approaches although recent advances in video techniques can provide limited size data (Watson et al. 2010, Harvey et al. 2012) (video techniques are discussed in detail in the section on refuge). Various baited and unbaited trapping techniques such as fence nets, pop nets and snake traps have been used in mangroves but with limited success (Vance et al. 1996). Furthermore, different responses of particular taxa to baits and various trap design modifications indicate that no one trap

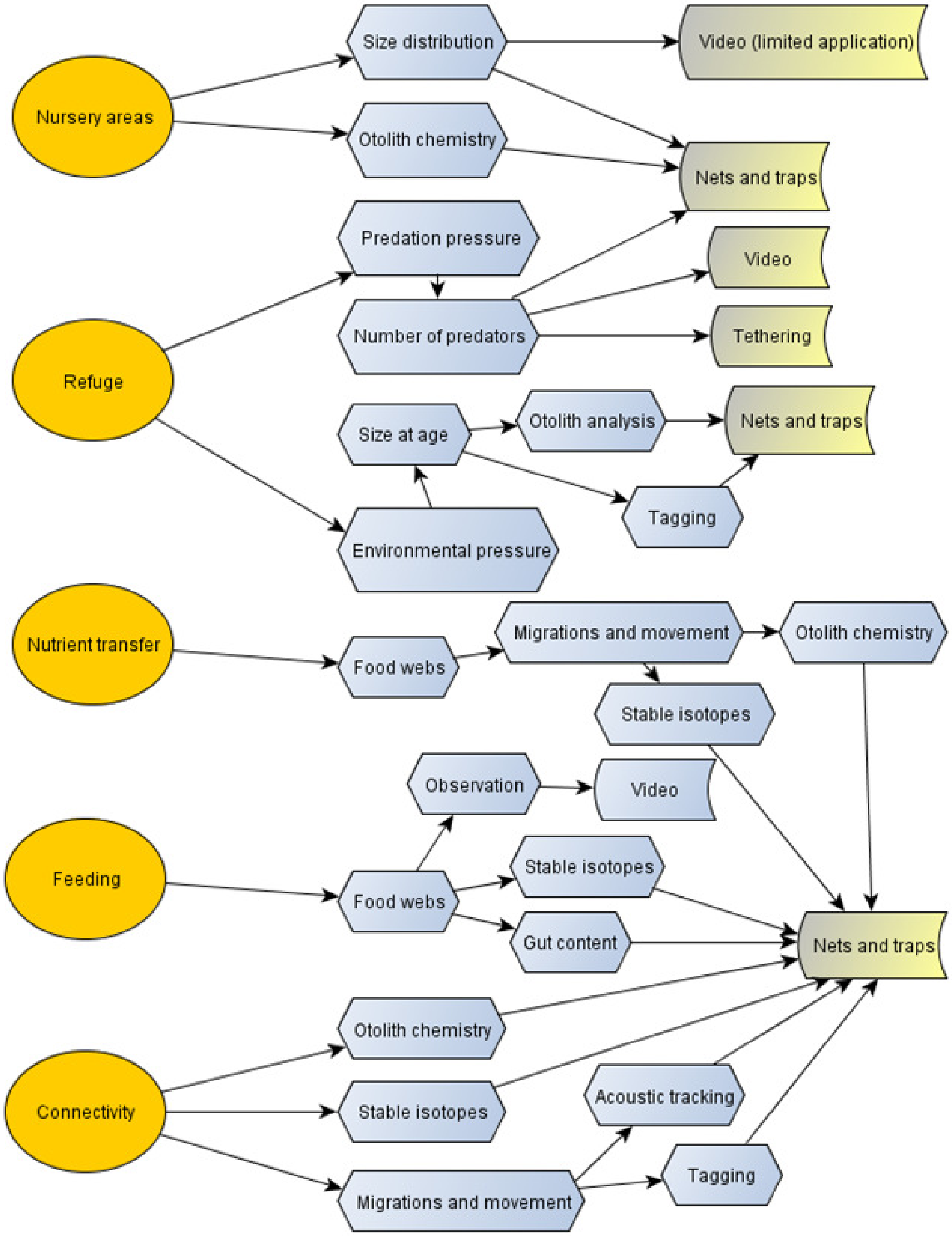

Figure 2: Functional roles of mangroves and the types of data and approaches required to investigate those functional roles.

design or mode of operation will be optimal for all species (Sheaves 1995) making it difficult to settle on the most appropriate design for a particular circumstance.

Netting approaches fall into two classifications, active and passive gears. The only active gear appropriate for assessing mangrove use by fishes is cast nets. Beam trawling adjacent to forests has been tried (Vance et al. 1990) however trawls are limited to circumstances where there is sufficient water for a tow boat. This means trawls can only be used in deeper water away from mangrove edges, or higher in the tide when there is sufficient water at mangrove edges. Higher in the tide fish can already be in forests and will not be sampled by trawls outside the forest. Seine nets have also been used along mangrove edges (Robertson & Duke 1990b), however the number of places where they can be effectively deployed is quite limited. Cast nets are an enclosure-type net that are deployed and immediately retrieved by the operator (Johnston & Sheaves 2007). Cast nets (Table 1) can only be deployed immediately adjacent to mangroves where they provide a good representation of the small fish fauna utilising edges (Johnston & Sheaves 2007) however they rely on proximity link fish to mangrove use. A key advantage of cast nets is that relatively high levels of replication are possible in relatively short timeframes compared to alternative netting approaches (Johnston & Sheaves 2008, Baker & Minello 2011). Monofilament cast nets can be easily damaged but they are not expensive to repair or replace. To provide consistent data from cast nets a high level of proficiency in deployment is required so that between-sample variability is minimised. Variability in sampling area adds unwanted random variability to the data, however this variability is largely negated if a single proficient operator is used throughout the study (Johnston & Sheaves 2008).

The most frequently used passive approach for netting mangrove fish is to “block net” along the edges of forests either with purpose designed nets such as Fyke nets or by anchoring seine or gill nets along mangrove edges. Fyke nets (Table 1) are probably the most efficient option and are usually deployed across drains where they exit mangroves (Lin & Shao 1999). Large Fyke nets can also be effectively deployed along mangrove edges (English et al. 1997). Again, these approaches imply that all trapped fish have been in the mangroves and that fish from outside mangroves were not been enclosed/trapped in nets during net deployments. Fyke nets, like all passive gears, require fish to be moving to sample effectively so sedentary fish that do not move around will not be sampled efficiently by any passive gear. Fyke nets are relatively easy to deploy but they only work efficiently in sites where mangroves drain completely so fish are forced to move out of mangroves on ebb tides. Only one replicate net sample is possible each ebb tide making it time consuming to achieve high levels of replication unless multiple nets are available.

Seine nets and gill nets (Table 1) are frequently used to examine fish assemblages (Perrow et al. 1996, Sheaves 2006). When sampling mangrove edges both approaches rely on association by proximity, because neither can be directly and effectively deployed in mangroves. Gill nets are a useful adjunct to other netting approaches because they are very effective at capturing larger, more mobile species (Robertson & Duke 1990a, Sheaves et al. 2006b) however they are also very size selective (Perrow et al. 1996, English et al. 1997) so several nets with different mesh sizes are required if a range of fish sizes is required (Gray et al. 2005). Small mesh gill nets suitable for capturing small fish are not generally very effective because even small monofilament mesh becomes visible to fish and avoidance levels increase. Net avoidance is also an issue for seine nets because fish are able to swim around the end/s or under leadlines as they are dragged along. Seines are also ineffective around structure or on very soft substrates (English et al. 1997, Rozas & Minello 1997). As with any passive gear, fish entangling in gill nets relies on fish movements whereas seine nets are an active enclosure approach providing a more effective method of capturing sedentary species.

Otolith chemistry provides historic information about habitats that a fish has utilised during its life through measurements of chemicals incorporated into the otolith matrix (Nagelkerken 2007, Murphy et al. 2012). As fish grow they lay down natural elemental and isotopic signatures in calcified structures such as otoliths (Gillanders 2005). These signatures, essentially natural tags, can be used to infer time spent in different ecosystems (Murphy et al. 2012). Because otolith material is continually being laid down and integrates trace elements from the water (Campana 1999), occupation history of habitats is recorded (Feutry et al. 2012, Harris et al. 2012, Lin et al. 2012). Consequently use of nursery habitats used can be inferred from otoliths of adult fish (Patterson et al. 1998, Murphy et al. 2012) provided sufficient information about the chemical composition of water in nursery habitats is available (Gillanders & Kingsford 2000). Otolith chemistry requires fish to be captured and otoliths removed and processed. Otoliths can be stored without deterioration until they can be processed. The advantage of this relatively new technique is that fewer fish need to be collected and specific-habitat related sampling is not necessarily required. The disadvantage is that processing of otoliths is not broadly available and processing is relatively expensive.

Table 1: Assessments of four net types for sampling in the Pacific based on in-field performance during mangrove fish sampling.

Net type	Advantages	Disadvantages
Cast net	• relatively easy to use with practice • can be deployed across any habitat lacking complex structure • fish equivalently across different habitats • provide comparable data among different habitats • rapid deployment-clear-redeploy time means high replication possible relative to alternative gears in a given timeframe • collect discrete, small-scale samples • high levels of replication offset some of the inherent variability in fish data • nets are easy and cheap to repair or replace	• requires practice and training to become proficient • areas sampled by net throws is variable (but does not introduce systematic bias and is partially offset by capability for high levels of replication) • larger more mobile fish are under-represented in catches • surface-dwelling species (e.g. mullet, garfish) under-represented in catches • monofilament nets are easily damaged
Fyke net	• easy to use • the only easy method that clearly isolates fish using mangroves from those using habitats adjacent to mangrove edges	• time consuming – relatively few replicates for a given time frame • avoidance and escape can be high • require sampling area to completely drain to be effective
Gill net	• easy to use • good for sampling larger more mobile species	• highly size and species selective • ineffective when fish are not moving • sampling area cannot be determined • captured fish often lost to scavengers during long soaks
Seine net	• easy to use • (possibly) less selective than many alternative gears • able to sample large areas	• labour intensive and can be slow to operate • can only be used on firm, unstructured substrates • net avoidance and escape can be high • catch efficiency is highly variable

Refuge

Mangroves are said to provide refuge to fish in two ways. Firstly, the complex structure provided by mangroves gives protection from predators (Robertson & Blaber 1992). Small fish are able to hide amongst the complex structure which acts as a visual barrier to predators and reduces the rate of predator-prey encounters, limits the abilities of predators to find and pursue their prey or physically excludes them due to their larger size (Manson et al. 2005b). Moreover, the mangrove canopy increases protection against avian predators because complex structure makes it more difficult for birds to hunt effectively (Manson et al. 2005b). Secondly, mangroves provide a “low energy” habitat where wave action (Massel et al. 1999) and current velocities (Mazda et al. 1997) are often reduced. The small energetic cost of using low energy habitats means more energy is potentially available for investment in growth (Niklitschek & Secor 2009, Stoll & Fischer 2011). This is a key facet of the nursery role of mangroves.

To understand whether fish are using mangroves for refuge, and exactly which benefits they may gain by the use of mangroves, is quite a complex issue. We can draw some implications about predation pressure experienced by prey species in mangroves by examining predator numbers in forests, a proxy for predator pressure (Fig. 2). Fish collection approaches for investigation of predator abundances are the same as those used for determination of mangrove nursery role, with the same issues and assumptions. A number of alternative approaches are available imcluding underwater video techniques, and prey tethering, each with their own advantages and limitations.

Video techniques, baited or unbaited, allow the presence of predators to be recorded (Harvey et al. 2007, Cappo et al. 2011), i.e. identify which species of predators enter mangroves, however enumeration of abundances is somewhat problematic because there are severe limitations on the type of abundance data that can reliably be extracted from videos (Harvey et al. 2012, Lowry et al. 2012). Independent abundance data, a requirement for most analytical approaches, is really limited to a measure of relative abundance, max-n (the frame with the greatest number of individuals of a species) (Cappo et al. 2011) consequently true abundances are likely to be underrepresented (Langlois et al. 2010). Video approaches are an ideal way to examine behaviours like feeding so may be ideal approaches understanding why fish enter forests (Murphy & Jenkins 2010). The effectiveness of videos can be limited by water clarity and a restricted field of view (i.e. small sampling area) although the latter can be somewhat offset by increasing replication. On a positive note, baited video can attract a wide range of species (Langlois et al. 2010, Murphy & Jenkins 2010, Watson et al. 2010, Lowry et al. 2012) or unbaited video will produce a relatively unbiased view of species using a particular habitat. Video approaches can generate large amounts of data rapidly and enable simultaneous sampling of different habitats.

Tethering as a means of assessing predation pressure is equivocal and there is much debate in the literature about data interpretation. Of particular concern is potential for experimental artefacts to interact with treatments (Peterson & Black 1994, Kneib & Scheele 2000, Haywood et al. 2003). For instance, in field situations, tethered prey are more vulnerable to predators than free swimming prey (Curran & Able 1998, Manderson et al. 2004). If this artefact interacts with treatments, i.e. tethered prey vulnerability varies among different habitat types, measures of predator activity cannot be separated from habitat effects rendering data potentially meaningless (Peterson & Black 1994, Kneib & Scheele 2000). At best, a tethering approach will generate a measure of predation potential, or relative predation pressure under an assumption that there is no effect of treatment (Aronson & Heck 1995).

To ascertain whether fish are using mangroves for refuge from environmental conditions (Fig. 2) rather than for predator avoidance, movement of individuals into and out of forests could be monitored using acoustic tagging techniques to track movements. Such an approach could also be employed to determine whether predators enter mangroves but has little application for assessment of predation pressure beyond confirmation of movements. Acoustic approaches can provide little more than movement information so understanding why fish use mangroves requires additional approaches be used as well. Acoustic tagging approaches are discussed more fully in the section on connectivity. Even with video it is probably not possible to separate predator avoidance from environmental refuge behaviours because observed feeding may only be incidental or opportunistic (Boaden & Kingsford 2012, Dixon et al. 2012) rather than regular practice. Feeding observations themselves only indicate that feeding occurs in mangroves, not that feeding is the only service provided because feeding doesn't preclude use as a refuge at the same time.

Measurement benefits obtained from use of low energy habitats requires demonstration of increased growth compared to alternative habitats. Size-at-age data can provide such information, particularly if it is complemented by growth rate studies, e.g. mark-recapture studies (Thompson & Hayes 2010). MR (or, capture, measure, tag, release, recapture, measure) information can provide relative growth rate data, and is almost the only way of obtaining such data under natural conditions (Pine et al. 2003). Radio and acoustic tags are beginning to be used more frequently for these applications however tagging equipment is relatively inexpensive when low-tech non-electronic tags are used. The main problems with MR are that recapture rates tend to be quite low (Penn & Farmer 1981, Sheaves et al. 1999, Pine et al. 2003) and they provide no information about where a fish has been in between release and recapture times (Chittenden et al. 2009). Low recapture rates (Boucek & Adams 2011) mean a large time investment to tag enough individuals is necessary to boost the probability of obtaining sufficient recapture information to allow valid analysis (Pine et al. 2003, Thompson & Hayes 2010). In any case the unknown between-capture movements mean that observed growth rates may also reflect benefits gained from non-mangrove habitats as well. However if MR is used in conjunction with chemical approaches it may be possible to interpret some of the movements of a fish between release and recapture times, at least at a broad scale (Lin et al. 2012). However it is unclear whether this method could differentiate between gains obtained from mangroves versus gains from adjacent habitats.

Nutrient transfer

Here we discuss food webs as a separate entity to feeding roles (Fig. 2). The context here relates to movement of nutrient between habitats and ecosystems through biological vectors, specifically fish in this instance. Species using mangrove forests are not limited to mangroves, but use them as part of a sequence of habitats connected by migrations for feeding, spawning, or ontogenetic habitat shifts associated with changes in size and/or diet (Secor & Rooker 2005, Cloern 2007). Such migrations can facilitate energy transfers among freshwater, coastal and offshore areas (Smith & Suthers 2000, Linke et al. 2001, Gillanders 2005, Saintilan et al. 2007, Feutry et al. 2012).

Organisms gaining benefit from mangrove productivity are not limited to just those species that enter mangrove forests. Many offshore species such as mackerel, trevallies and sharks undertake inshore migrations to access important coastal feeding areas (Begg & Hopper 1997, Barnett & Semmens 2012) where mangrove-associated species become an important food source (Sheaves 2009). Here, energy acquired from mangrove habitats is moved offshore to benefit other ecosystems. These types of energy transfer are called trophic relays (Begg & Hopper 1997, Nemerson & Able 2003, Stolen et al. 2009) and provide clear evidence that even mangrove species with no fisheries value require careful management to maintain food web integrity (Sheaves 2009).

Similar trophic links between mangrove and other habitats occur through fish migrations (Polis et al. 1997).

Understanding trophic relays between habitats and ecosystems requires sound knowledge of both movements of fish and of their diets. Without the aid of chemical approaches it would be prohibitive to sample exhaustively enough to know where and when particular species of fish move, what they eat, as well as movements and diets of their prey, let alone the ultimate sources of nutrition supporting them. Information about nutrient transfer is best extracted from chemical approaches where the aim is to identify the ultimate sources of carbon underlying particular food webs. This approach contrasts with gut content studies that only provide just short-term feeding patterns (Speed et al. 2012) however though those short-term patterns can assist interpretations from chemical approaches. Otolith chemistry and stable isotope analysis (SIA) provide different information about dietary history. As previously discussed otoliths are aggregation points for naturally occurring elemental and isotopic signatures (Gillanders 2005) because they incorporate chemical information from the water however otoliths also record dietary history (Campana 1999). Consequently micro-chemical analysis of isotope signatures across otoliths can be used to obtained some life-history dietary information. Use of otolith chemistry for movement and dietary studies has similar benefits and drawbacks to its application for nursery ground identification.

In much the same way that otoliths record diet history, fish tissues can provide information about fish dietary histories (Ankjaero et al. 2012). Examination of otoliths and tissues is often preferred over examination of gut content for linking feeding to movement patterns. Gut content analysis only provides information about the most recently ingested material whereas SIA allows inference about longer-term patterns (Estrada et al. 2003, Speed et al. 2012) hence it can incorporate dietary information from distant habitats (Abrantes & Sheaves 2008). The incorporation of prey isotope ratios into predator tissues occurs in a predictable manner (Peterson & Fry 1987, Estrada et al. 2003) and different tissues incorporate and sustain those isotope signatures over different timescales (Ankjaero et al. 2012). When used in conjunction with gut content analysis and otoliths chemistry SIA can provide extensive dietary history.

One strong advantage of SIA is that relatively few fish need to be sacrificed to obtain reliable information and if individuals are large enough tissue samples can be collected by biopsy with no long-term effects on their health. Another advantage over gut content analysis is that SIA records information on dietary items that are assimilated so incidentally ingested materials that don't contribute to nutrition are not recorded (Abrantes & Sheaves 2009). SIA samples are relatively easy to collect once fish have been captured and require minimal equipment and access to a drying oven for processing. There are many laboratories capable of processing samples, most at a reasonable cost, so SIA is a relatively accessible approach in most areas. Perhaps the largest drawback to the SIA approach is that it cannot provide the level of taxonomic definition of prey that gut content analysis can provide (Speed et al. 2012), however such levels of definition are not always required.

Feeding

Mangroves are considered to be important feeding habitats which is one reason why said to be important nursery habitats (Robertson & Blaber 1992). Several studies have used SIA to investigate links between mangroves and fish (Manson et al. 2005a, Manson et al. 2005b, Meynecke et al. 2007) and mangroves and prawns (Loneragan et al. 1997, Chong et al. 2001, Vance et al. 2002, Meager et al. 2003) yet there are few studies that have attempted to determine the precise details of what food resources are obtained from mangroves by fish and crustaceans. Understanding precisely which mangrove components contribute to fish and crustacean diets is an essential underpinning to assessment and management of mangroves and of the food webs and other ecosystems they support (Fig. 2).

Feeding behaviours recorded using video techniques and SIA can provide some insights into which mangrove resources are being utilised as food but neither will reliably identify specific organisms as prey species. Additional advantages and limitations of both techniques have been previously discussed. The most consistent approach for arriving at a detailed taxonomic level of dietary information is through gut content analysis (Speed et al. 2012) however, as with any approach, there are limitations to inferences that can be drawn (Baker et al. 2013).

Although gut content analysis provides information on the most recently ingested food items (Speed et al. 2012) not all materials in a gut are identifiable (Schafer et al. 2002, Baker et al. 2013). How identifiable ingested items are depends on the level of digestion and this depends on time since ingestion, the type of prey item (MacDonald et al. 1982, Legler et al. 2010) and the way predators handle and ingest food (Scharf et al. 1997). Although it may seem immaterial, the types of gear used to collect fish can have major impacts on dietary data (Baker et al. 2013). Extracting gut content data from passive sampling gears that accumulate fish over time such as gill nets (Salini et al. 1990), long lines (Barnett et al. 2010) and Fyke nets has the problem that digestion is ongoing as long as fish remain in the gear (Rozas & LaSalle 1990, Haywood 1995) and in enclosure type gears like Fyke nets trapped predators are able to continue feeding (Olla et al. 1997) and may ingest species other than their normal diet because they are concentrated in the net enclosure.

Despite the limitations to the use of gut content analysis discussed here, and other limitations discussed eloquently in Baker et al. (2013), gut content analysis remains a useful tool for examining the feeding role of mangroves. Perhaps the greatest limitation for application in Pacific Island countries is the dearth of experienced researchers with sufficient breadth of knowledge to reliably identify food items at a detailed taxonomic level.

Connectivity

Connectivity is an integral component underlying each of the previous four mangrove roles (Fig. 2). We include connectivity as an independent role because it is essentially the link that binds habitats together in time and space. Subsequently, connectivity underpins food web dynamics, movements of nutrients between habitats, migrations of fish to gain refuge or to enter and exit nursery areas (Sheaves 2009). Disruptions to connectivity have flow-on effects throughout affected ecosystems (Secor & Rooker 2005). Understanding and documenting connectivity is an important component of ecosystem management and there are several approaches that can provide relevant data. All approaches relate to understanding the movements of fish over time: tagging (long-term external anchor tags), otolith chemistry, stable isotope analysis and acoustic tagging. The former three have been discussed in earlier sections, tagging and otolith chemistry associated with protection and stable isotopes for nutrient transfer.

In recent years acoustic tagging techniques have undergone substantial development and increased scientific acceptance (Cooke et al. 2011) for studies of fish migrations (Jellyman 2009). Electronic tags (e.g. passive integrated transponders [PIT], acoustic telemetry, radio telemetry) can be attached to fish externally or inserted internally (Cooke 2008, Brown et al. 2011). Acoustic tags have an enormous potential for gathering information about fish movements however they also have limitations (Bridger & Booth 2003, Brown et al. 2011). Rates of tag retention for external tags can be quite low, interfere with swimming ability and increased susceptibility to predation (Thorstad et al. 2001). Gastric tag retention is also poor unless fish aren't feeding (Brown et al. 2009). Intracoelomic tags, those surgically implanted in the coelom (visceral cavity) of fish, provide improved retention rates so are more suitable for longer-term monitoring (Jepsen et al. 2002, Bridger & Booth 2003), however this practice raises the stakes for ethical issues in research (Brown et al. 2011) and requires operatives trained in surgical techniques and the use of anaesthetic agents.

Effective life-span of acoustic tags can be relatively short, although newer equipment can offset this somewhat with pre-programmed 'on-off' periods (Jellyman 2009) although that type of operation can reduce the probability of recording movements. Evidence suggests that passive recording stations can underestimate movement patterns (Claisse et al. 2011) suggesting that, like any sampling approach, caution is required in interpretation of outcomes. Background 'noise' levels can interfere with signal range and clarity (Lucas & Baras 2000) but perhaps the major drawback of acoustic approaches is the equipment cost (Cooke et al. 2011). High equipment cost means relatively few individuals can be monitored for a given budget (i.e. low replication rate and/or a limited number of species). Both tags and recording stations are expensive and in most instances several recording stations are required to produce a meaningful outcome (Cooke et al. 2011) which means studies have to be well funded to be successful. On a positive note marrying acoustic approaches with otolith microchemistry and SIA has much potential to provide strong insights into fish movement studies and provide better understanding of fish life histories (Jellyman 2009).

MESCAL-specific performance of sampling gears

In-country sampling of fish in demonstration sites was conducted during the latter half of 2012 in all countries. Data generated from that sampling and forwarded to James Cook University (JCU) for processing had numerous problems that have to date prevented extensive analysis. Specific problems with those data will be detailed in a separate report and here we focus on performance of the four different sampling gears used for the MESCAL study.

All fish sampling for the MESCAL project was undertaken by in-country operatives who had attended training sessions for each of the sampling gears. Operators with prior experience of the four net types and sampling protocols were not present during fish sampling making in-field performance of the gears difficult to ascertain. Consequently assessment of the effectiveness of sampling equipment can only be derived from the data provided, our prior experience with the equipment, and our perceptions of training outcomes during workshops. Here we explore catch data as an aid to assessment but the primary focus is, and should be, on ease of use by operators with minimal training and experience, and whether the equipment was appropriate for sampling mangrove fish faunas in the Pacific. Catch data itself should be interpreted very cautiously because as stated there were many problems in the data and there were no baseline data available to determine whether sampling gears produced data that was representative of country-specific mangrove fish faunas.

Total abundance of fish was very low for all countries (Table 2) given the level of sampling effort. This is typical of mangrove fish populations that are suffering from severe overfishing, however in this instance a lack of on-ground experience with sampling equipment may have also contributed to small catches. In Fiji, Tonga and Vanuatu a majority of fish were captured in cast nets and Fyke nets. In the Solomon Islands (SI) and Samoa, the two countries where cast nets performed relatively poorly most fish were caught in Fyke nets and seine nets. The difference in SI and Samoa is most likely because operators were not as proficient with cast nets as in other countries.

Table 2Table 2: Summary catch statistics for MESCAL in-country sampling.

Country	Sampling gear	Total fish abundance	Number of taxa: scientific name[1]	Number of taxa: common name[2]
Fiji	Cast net	301	16	2
	Fyke net	339	17	7
	Gill net	99	22	1
	Seine net	106	9	4
	Total	**845**	**42**	**9**
Samoa	Cast net	157	8	2
	Fyke net	916	16	2
	Gill net	169	11	1
	Seine net	196	17	6
	Total	**1438**	**26**	**8**
Solomon Islands	Cast net	4	1	3
	Fyke net	126	1	16
	Gill net	4	2	1
	Seine net	10	0	5
	Total	**144**	**4**	**18**
Tonga	Cast net	64	7	1
	Fyke net	61	6	0
	Gill net	1	0	1
	Seine net	8	3	2
	Total	**134**	**10**	**3**
Vanuatu	Cast net	260	4	11
	Fyke net	54	2	7
	Gill net	0	0	0
	Seine net	14	3	6
	Total	**328**	**9**	**19**

[1] Taxonomic identifications provided for Fiji are expected to be correct although no photographs have been provided to allow validation of identifications. Approximately 20% of taxa from the remaining countries have not had their scientific names validated because photographs have not been provided. Numbers provided here should be interpreted with caution because many incorrect scientific identifications were made in-country however where good quality photographs were provided identifications have been corrected.

[2] At present an absence of photographs means that many taxa have only local or common names provided. In the absence of photographs further identification is not possible.

It is difficult to be confident with identifications of taxa because there were many instances of incorrect identification among taxa for which photographs were provided to JCU. Estimates of taxonomic richness, number of taxa, is presented (Table 2) but should be interpreted cautiously. Fiji appears to have provided the most reliable data, a majority of taxa identified to the level of genera or species by fisheries personnel; however we are yet to confirm those identifications because no photographs have been provided. In other instances few photographs have been provided and we were left with only local names so were unable to proceed further with identification. There were few clear patterns in the number of taxa collected by different net types but Fyke nets were always prominent. Fyke and gill nets performed well in Fiji, fyke and seine nets well in Samoa and SI, and Fyke and cast nets were effective in Tonga and Vanuatu.

Gear efficiency and cost effectiveness of sampling is always an important consideration but caution in interpreting effectiveness of sampling gears is important. When data are examined as catch per net (CPN), it is clear that Fyke nets caught most individuals, with cast nets and seine nets ranked second in two countries and gill nets second in one (Table 3). Those rankings were based purely on abundance per 50 nets and made no allowance for time required to set and retrieve nets and samples, an important consideration in cost benefit trade-offs, so an adjusted CPUE estimate ($CPUE_{est}$) was constructed to incorporate a time function. By necessity $CPUE_{est}$ needed to be an estimate because data delivered from MESCAL in-country sampling and required to incorporate time into CPUE calculations was incomplete. Cast nets produced the most favourable $CPUE_{est}$ across all countries except SI where seine nets produced highest $CPUE_{est}$. In Fiji, Samoa, Tonga and Vanuatu cast net sampling was more than twice as effective as the next best gear type.

Table 3: Catch per net (CPN) and estimated catch per unit effort (CPUEest) for the four sampling gears used in the MESCAL in-country sampling.

Country	Sampling gear	CPN[1]	$CPUE_{est}$[2]
Fiji	Cast net	45.6	68.4
	Fyke net	269.8	5.4
	Gill net	47.1	3.8
	Seine net	101.9	30.6
Samoa	Cast net	82.6	123.9
	Fyke net	1117.1	22.3
	Gill net	162.5	13.0
	Seine net	92.5	27.7
Solomon Islands	Cast net	2.1	3.1
	Fyke net	239.7	4.8
	Gill net	6.0	0.5
	Seine net	35.7	10.7
Tonga	Cast net	56.1	84.2
	Fyke net	305.0	6.1
	Gill net	3.8	0.3
	Seine net	40.0	12.0
Vanuatu	Cast net	203.1	304.7
	Fyke net	245.5	4.9
	Gill net	0.0	0.0
	Seine net	53.8	16.2

[1] CPN: calculated as mean number of fish per 50 nets

[2] $CPUE_{est}$: CPUE once cast, seine and gill nets standardised to match with average time to collect a single fyke net sample, i.e . standardised to 5 hours sampling time. Estimates of the number of nets possible over a five hour period are conservative; cast = 75, fyke = 1, gill = 4 (based on 1 hr soaks), seine = 15

A lack of more definitive evidence means we have to assume that fish assemblages were reasonably well represented and use $CPUE_{est}$ as an assessment tool to link gear effectiveness to ease of use and versatility (number of habitat types they can be used to sample). A lack of on-ground expertise during sampling, and a lack of background data about local fish assemblages, means ease of use and versatility of sampling gears must become the primary criteria for determining appropriate approaches for future sampling of mangrove fish assemblages in the Pacific.

All four fish sampling gears used during the MESCAL project were relatively easy to use (Table 1). During training sessions cast nets passed the greatest difficulties for in-country operatives, however regular practice should have rapidly negated this issue. Cast nets generally produced the best CPUE_{est} suggesting that most operators were relatively proficient with the equipment by the time sampling was conducted. Levels of replication set out in country-specific sampling protocols for cast nets were achieved in all countries. This indicates that replication levels for cast nets were not too ambitious and higher levels of replication should be possible as operators become more proficient with equipment and protocols. Higher replication levels can offset a major disadvantage of cast nets (variable sampling areas), however large fish and surface-dwellers will usually be under-represented in catches. This is only a disadvantage when quantitative data is required but is not an issue when more robust presence-absence data is used. Cast nets were clearly a successful approach for collecting mangrove fish data for the MESCAL project.

Fyke nets were relatively effective at capturing fish exiting mangrove forests in the Pacific and were the only gear capable of discriminating those species entering mangroves from those using adjacent habitats (Table 1). Although net avoidance and escape can be high the ability to isolate species using mangroves is valuable. Gill nets have many problems associated with their use however their ability to sample larger individuals, an area where the other three methods are less efficient, made gill nets a useful approach for the MESCAL project.

Seine nets were less effective in many MESCAL demonstration sites because they could not be used effectively in most mangrove-associated habitats (Table 1). Species captured in seine nets were often present in catches from other net types so although seine nets are easy to use and possibly less species and size selective than other approaches their effectiveness was limited to a single habitat type. This makes them less useful across the spectrum of mangrove settings encountered in the Pacific.

Solutions for the Pacific

Assessment of the functional roles of mangroves in fisheries productivity is a difficult problem that has not been satisfactorily addressed in any country (Johnston & Sheaves 2007) despite general understanding that mangroves play a pivotal role in many fisheries (Manson et al. 2005a, Aburto-Oropeza et al. 2008, Hussain & Badola 2010). Arriving at estimates of the value of mangroves to fisheries, and the people that rely on mangroves, may be even more difficult, with present valuations likely to highly underestimate their worth (Barbier 2000, O'Garra 2012). Assessing functional roles of mangroves in the Pacific is made more difficult by the lack of technical expertise and scientific experience on-ground in Pacific Island countries.

The present MESCAL project recognised that a lack of experienced people on-ground meant that only basic approaches could be relied on to produce sensible outcomes. Consequently netting approaches were used to assess mangrove roles in fisheries productivity yet, as previously stated, problems related to lack of sampling and data handling experience surfaced and compromised what should have been quite robust data. Based on this outcome it would be inappropriate to suggest changes to the existing sampling approach until local operators had gained sufficient experience to deliver reliable outcomes. However we would strongly recommend that further training be implemented in the use of equipment and the recording, handling and reporting of data before additional sampling is undertaken. Further, we would recommend having an expert on-ground during initial repeats of the sampling to oversee protocols and contribute experience that can be passed on to local operators.

There are many alternative approaches that have much potential to address the question at hand, and would be suited to use in the Pacific were expertise and equipment readily available. Otolith chemistry, stable isotope analysis and acoustic tagging approaches have many advantages over conventional netting and other approaches but they can be very costly and require appropriate skills to implement. At present we don't believe such approaches could be implemented for Pacific Island countries without considerable investment of funds and overseas expertise however we are of the opinion that much could be gained by incorporating such approaches into future planning.

Recommendations

1. There is a crucial need for more extensive training in all aspects of mangrove fish sampling approaches. Training workshops and in-field instruction is necessary to develop greater understanding equipment operation and of identification and avoidance of potential problems.
2. There is a crucial need for more extensive training in all aspects of data recording, handling and reporting. Training workshops and in-field instruction is necessary to develop greater understanding recording requirements and protocols. Further, workshops addressing issues surrounding data handling and reporting are necessary before analytical capability for interpretion of data can be addressed.
3. Data analysis capability is at a very low level and this needs to be addressed. Workshops and/or intensive courses are required to improve this situation.
4. Fish taxonomy skills need to be developed as matter of urgency. Few operatives were capable of providing reliable species identifications and/or reliable information to allow remote identification from descriptions and photographs. Development of taxonomic skills should incorporate a photographic skills component that ensures clear images of diagnostic morphologies are produced.
5. All training programs (workshops, in-field instruction, intensive courses) should be focussed at a selection of local personnel who will become "dedicated" operators, i.e. operators earmarked to become leaders responsible for particular aspects of mangrove fish research, including in-field sampling and data analysis. Not only should dedicated personnel be developed to improve in-country capabilities, those personnel should be encouraged to pass their skills on to other operatives to build a pool of experienced personnel so skills are not lost as experienced people move away or change roles.
6. In the absence operators with substantial in-field experience, basic netting approaches should be retained for mangrove fish sampling. Additional training should be sought, and whenever possible experienced local personnel should be enlisted to assist and external experts retained to oversee operations.
7. We suggest continued use of cast nets, fyke nets and gill nets is the best way forward for the Pacific. There are too few habitats where seine nets can be effectively deployed so time

previously apportioned to seine netting could be used more efficiently by collecting additional cast net samples.

8. Chemical approaches will make a valuable contribution to understanding the values of mangroves to fisheries so they warrant consideration. However the level of expertise required to undertake such studies is not present in the Pacific so any project would almost certainly have to be heavily supported and managed by external experts rather than Pacific Island nationals.

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